Evaluation of MERRAero (MERRA Aerosol Reanalysis)

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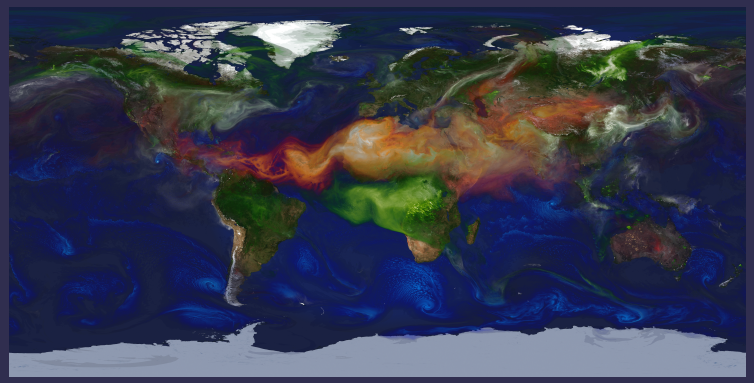
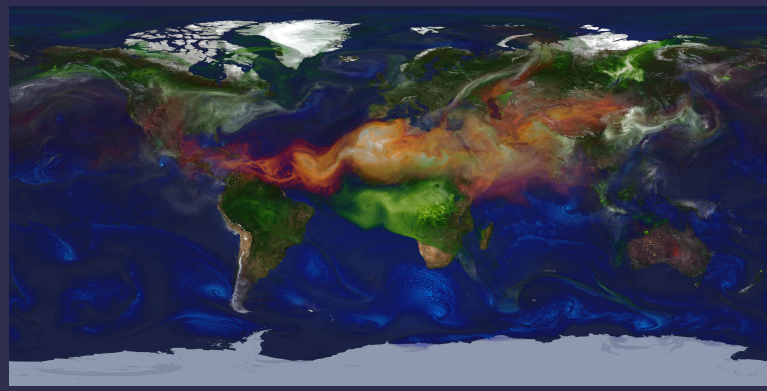


JCSDA workshop, 14 May 2015

Introduction

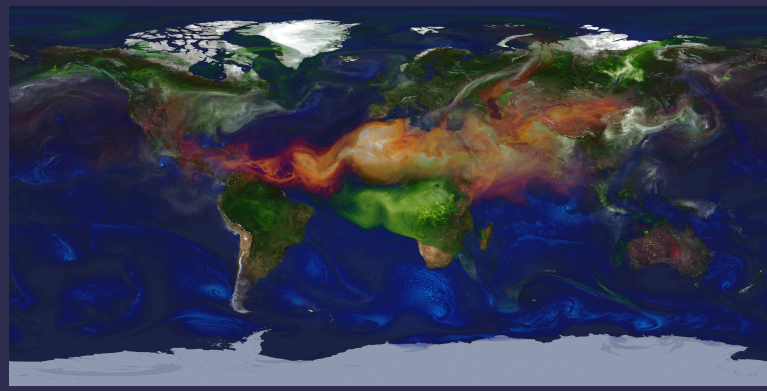


- **MERRA Aerosol Reanalysis (MERRAero)**

is the first aerosol reanalysis produced at GMAO :

- based on a version of the GEOS-5 model radiatively coupled to GOCART aerosols,
- assimilation of bias corrected Aerosol Optical Depth (AOD) from the MODIS sensor on both Terra and Aqua satellites.

Introduction



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  - based on a version of the GEOS-5 model radiatively coupled to GOCART aerosols,
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- **Two different ways of validating MERRAero:**

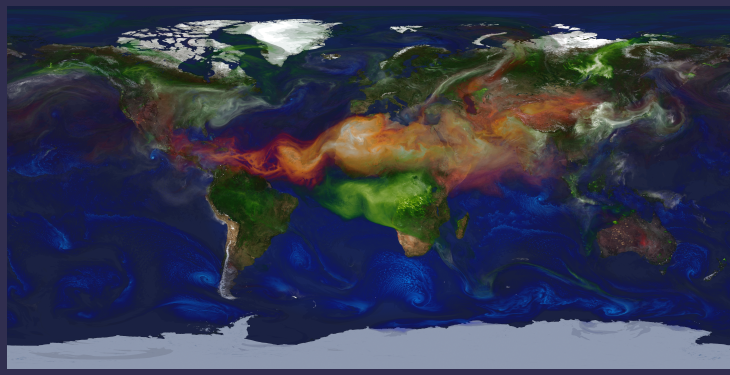
1) **Absorption:**

  - Effect of aerosols on climate system depends :
    - on the total aerosol concentration,
    - on the radiative or optical properties of the particles.

  In MERRAero : absorption is not constrained by observations.

➢ We used OMI/AURA AI measurements and AAOD retrieval as independent validation for MERRAero absorption.

Introduction



2) Surface concentration:

- $PM_{2.5}$ fine particulate matter with diameter less than 2.5 um:
  - Negative effects on regional air quality and on human health,
  - Ways to monitor:
    - Global monitoring networks -> but offer sparse geographic coverage,
    - Satellite measurements, especially AOD -> large spatial coverage but limited to cloud free conditions, uncertainties on AOD retrievals and how do you relate PM2.5 to AOD,
    - Combination of satellites retrievals and model,
    - Data assimilation of AOD in model→ MERRAero.

➢ We used EPA-AQS and IMPROVE surface PM2.5 measurements to assess the quality of simulated surface PM2.5 in MERRAero.

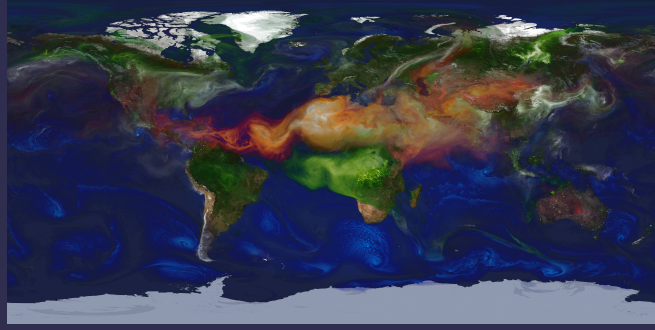
Outline

- MERRAero overview
- Evaluation of MERRAero absorption
- Evaluation of MERRAero surface $PM_{2.5}$
- Conclusions

Summary of GEOS-5 Reanalysis Activities

Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979-present	NONE	now
MERRAero	50 km	2002-present	MODIS C5	now
FP for Inst. Teams	50 km	1997-	MODIS C5	In progress
NCA	25 km	2010-11	MODIS C5, MISR	Now
MERRA-2 Not discussed here	50 km	1979-present	AVHRR, MODIS C5, MISR,AERONET	Summer 2015
MERRA-2 Dynamical Downscaling	12.5 km	2000-2015	AVHRR, MODIS C5/C6, MISR, AERONET	Q4 2015

MERRAero Overview (1)



Feature	Description
Model	GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA Meteorology (Replay) Land sees observed precipitation (like MERRALand) Driven by QFED daily Biomass Emissions
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) NNR AOD: Neural Net Retrievals • Based on MODIS "Level 2" reflectances • Trained on AERONET Retrievals Stringent cloud screening
Period	mid 2002-present (Aqua + Terra)
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

MERRAero Overview (2)

Analysis Splitting

3D Aerosol Concentration Analysis

$$x^a = x^f + P^f H^T \left(H P^f H^T + R\right)^{-1} \left(y^o - H x^f\right) \equiv x^f + \delta x^a$$

where y is AOD, and x is aerosol concentration.

2D AOD Analysis

Since the AOD observable is 2D is common to solve the AOD analysis equation:

$$y^a \equiv H x^a = y^f + H P^f H^T \left(H P^f H^T + R\right)^{-1} \left(y^o - H x^f\right) \equiv y^f + \delta y^a$$

Projecting AOD into Concentration Increments

The 3D concetration increments is related to the 2D AOD increments by:

$$\delta x^a = P^f H^T \left(H P^f H^T\right)^{-1} \delta y^a$$

For efficiency, this last equation can be solved in 1D (vertical).

MERRAero Overview (3)

Analysis Splitting with Ensembles

If the background error covariance P^f is parameterized in terms of ensemble perturbations, say

$$\begin{aligned} X &= (x_1 \quad x_2 \quad \cdots \quad x_E) \\ Y &= HX \\ &= (Hx_1 \quad Hx_2 \quad \cdots \quad Hx_E) \\ &= (y_1 \quad y_2 \quad \cdots \quad y_E) \end{aligned}$$

so that

$$P^f \sim XX^T$$

it follows that

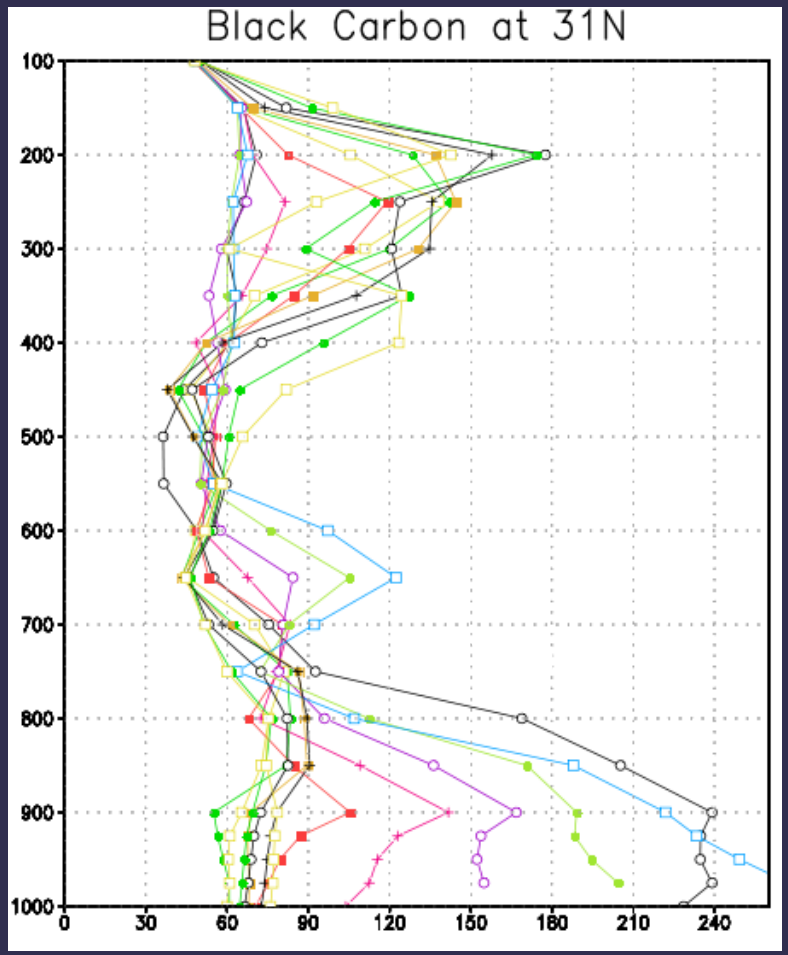
$$\delta x^a = XY^T \left(YY^T\right)^{-1} \delta y^a$$

This is the well known (unbiased) linear regression equation.

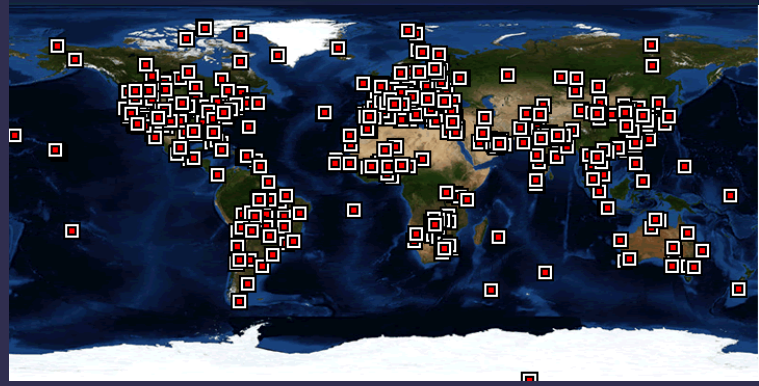
MERRAero Overview (4)

Local Displacement Ensembles (LDE)

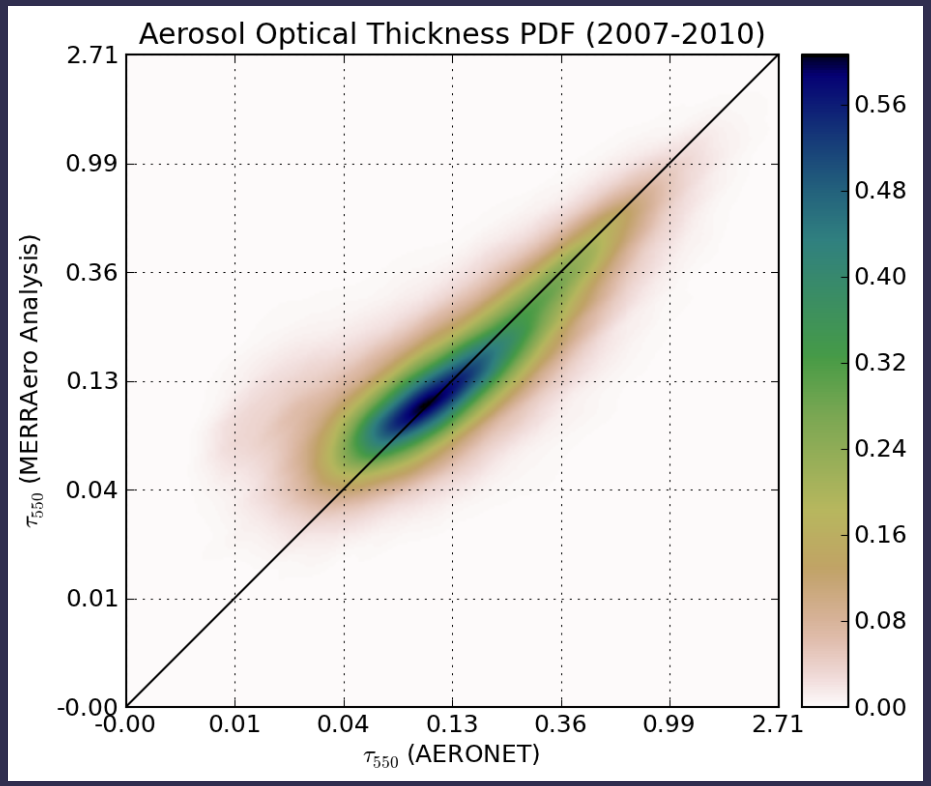
- Construct perturbation ensembles by means of isotropic displacements around gridbox
- Weigh each ensemble member by its fit to 2D AOD analysis
- For efficiency, perform the AOD-to-mixing ratio calculation in 1D



MERRAero Overview (5)



Independent AERONET AOD evaluation



Evaluation of MERRAero Absorption

AI observed/simulated comparison (1)

AI : Qualitative indicator of the presence of absorbing aerosol (AI > 0)

AI is derived from the change in the spectral dependence of the back-scattered UV radiances induced by aerosols relative to the Rayleigh scattering between 354 and 388 nm [Torres et al., 1998, 2007].

$$AI = -100\left[\log_{10}\left(\frac{I_{354}^{Obs}}{I_{354}^{calc(Ray)}(R_{388*}^{Obs})}\right)\right]$$

AI depends on :

- aerosol concentration
- aerosol layer height
- aerosol optical properties

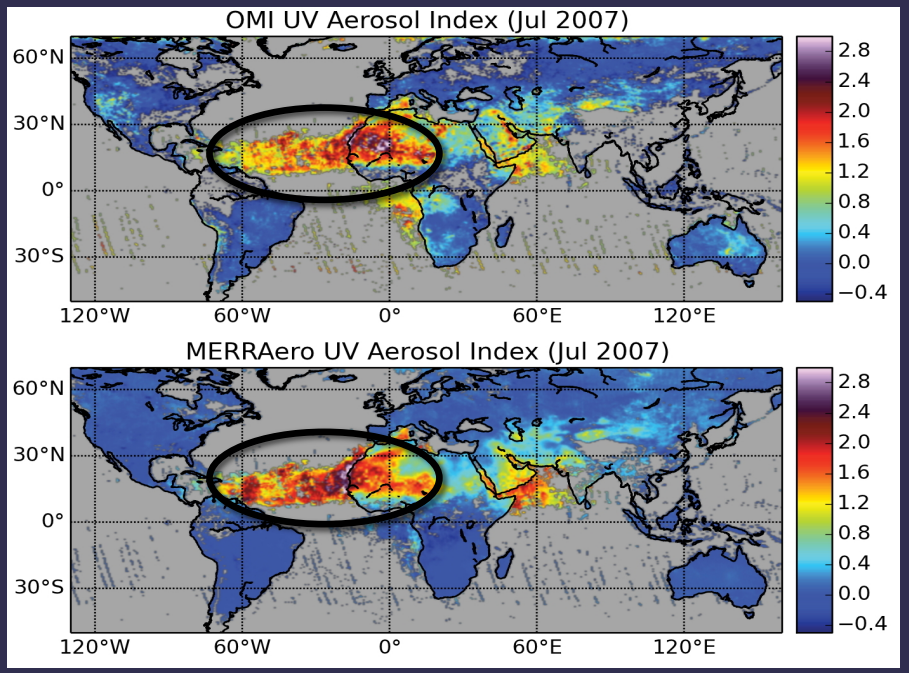
MERRAero simulated radiances and AI: Radiative transfer code VLIDORT

[Spurr et al., 2002, 2006].

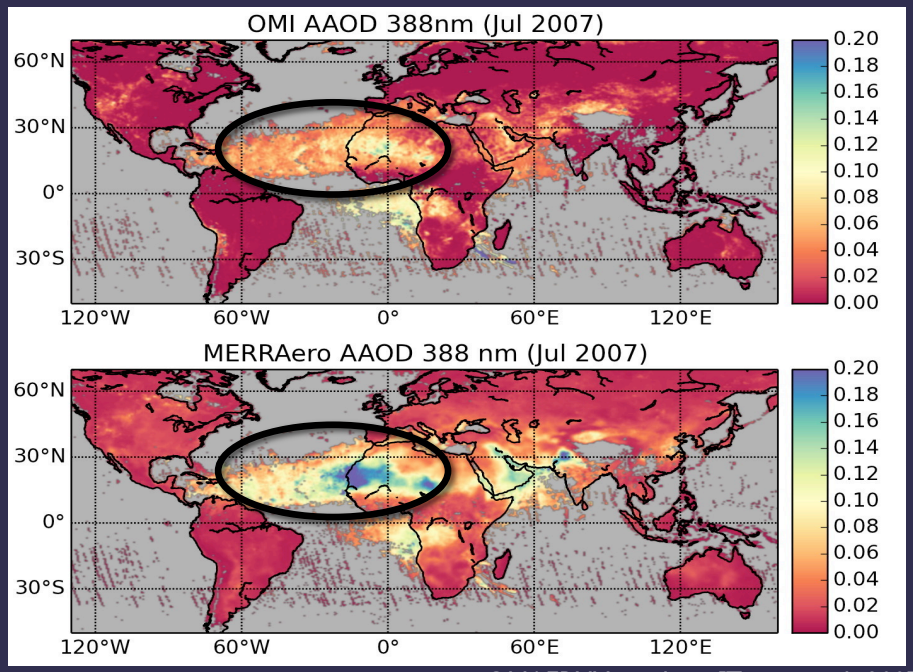
AI observed/simulated comparison (2)

RESULTS (baseline simulation)

AI



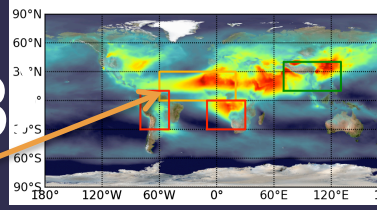
AAOD



OMAERUV product [Torres et al., 2007]

- Globally MERRAero AI captures major features but :
  - Tend to underestimate over North America, South America and more importantly in the Southern Africa Biomass burning region.
- MERRAero AAOD greater than OMI AAOD at 388 nm:
  - Saharan dust region → conflicted diagnosis

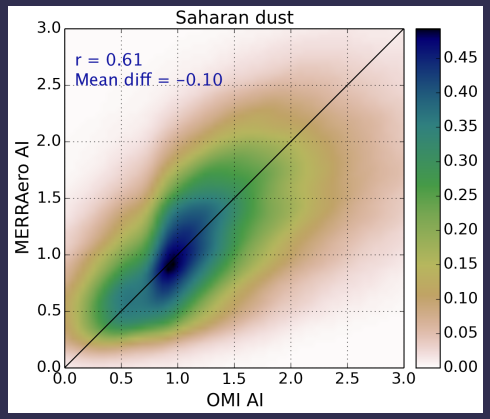
AI observed/simulated comparison (3



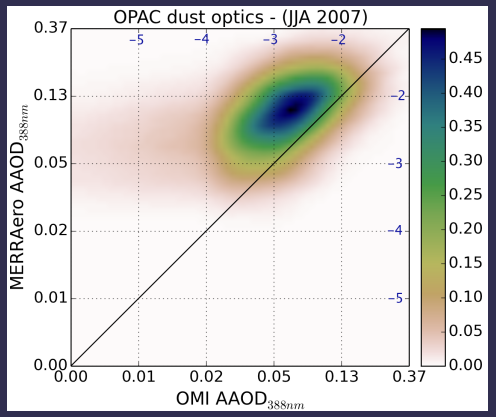
Saharan dust

Baseline simulation :

AI



AAOD

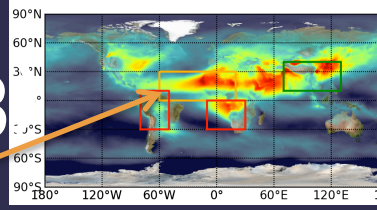


OMAERUV product

[Torres et al., 2007]

Fraction of MERRAero AAOD from DUST aerosol > 0.7

AI observed/simulated comparison (3

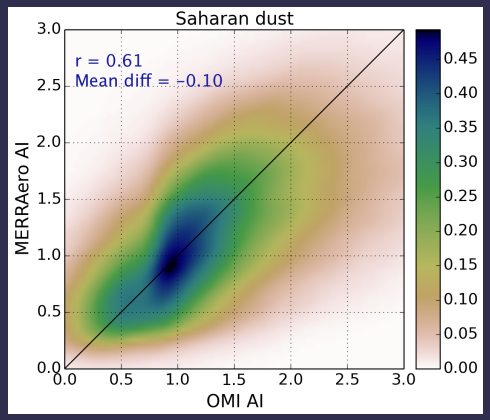


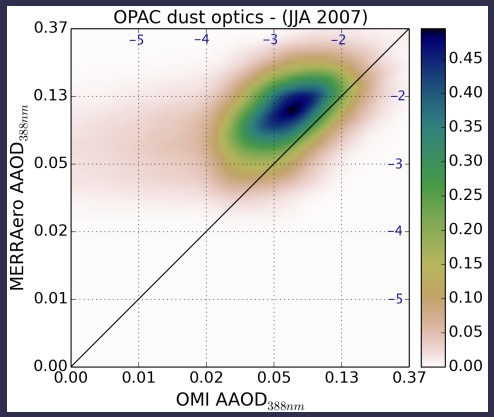
Saharan dust

AI

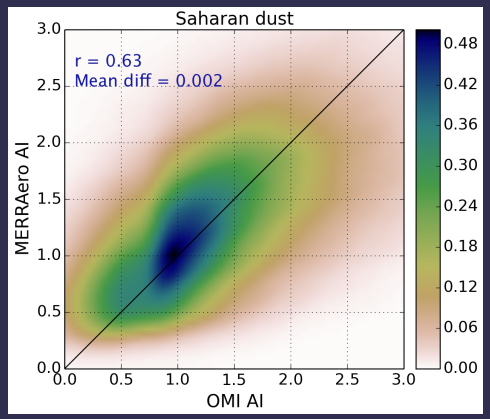
AAOD

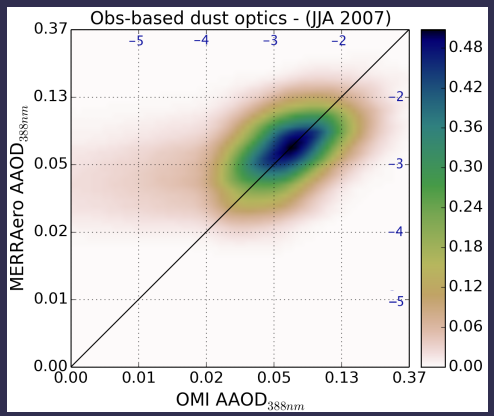
Baseline simulation :





Updated simulation :



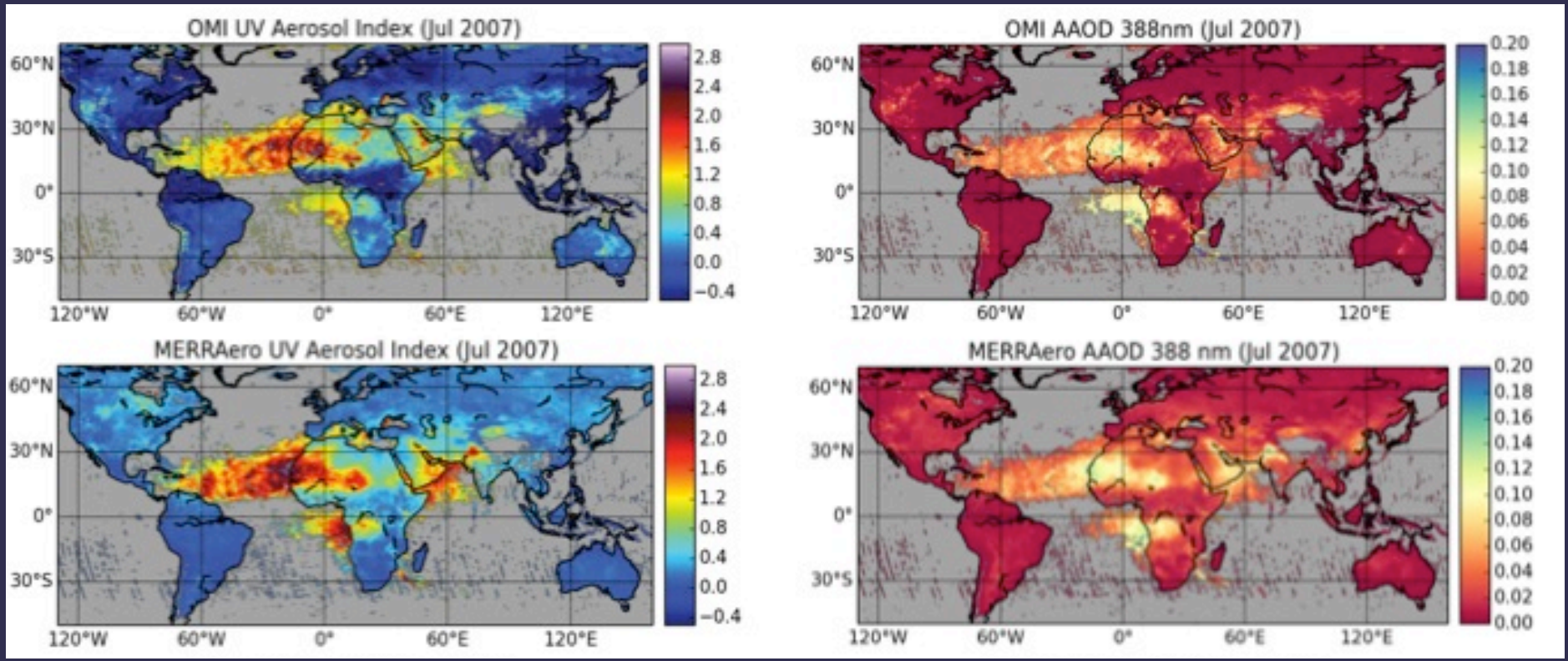


Fraction of MERRAero AAOD from DUST aerosol > 0.7

AI observed/simulated comparison (4)

RESULTS (updated simulation)

AI **AAOD**

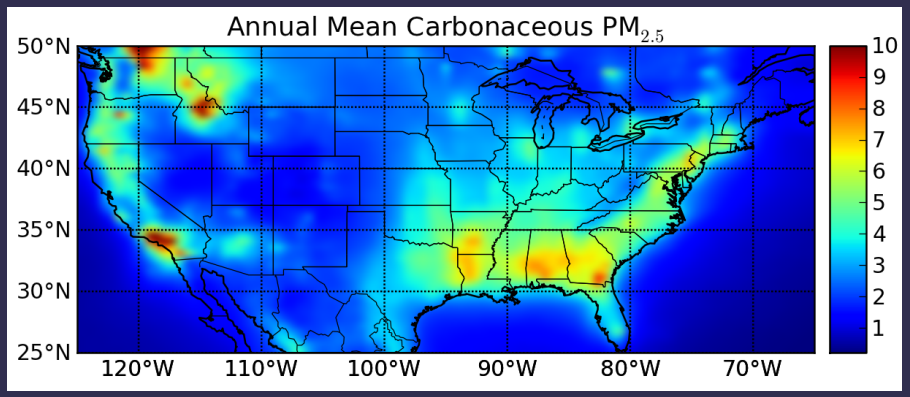


More details can be found in Buchard et al., ACP, 2015

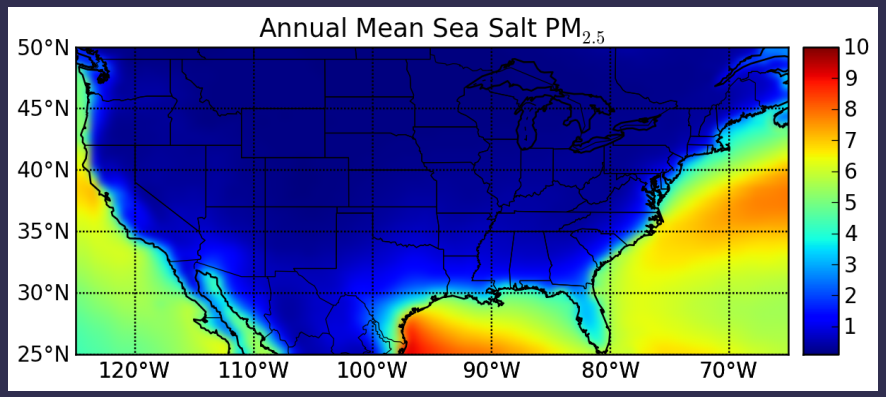
Evaluation of MERRAero Surface PM2.5

Evaluation of Surface PM2.5 (1)

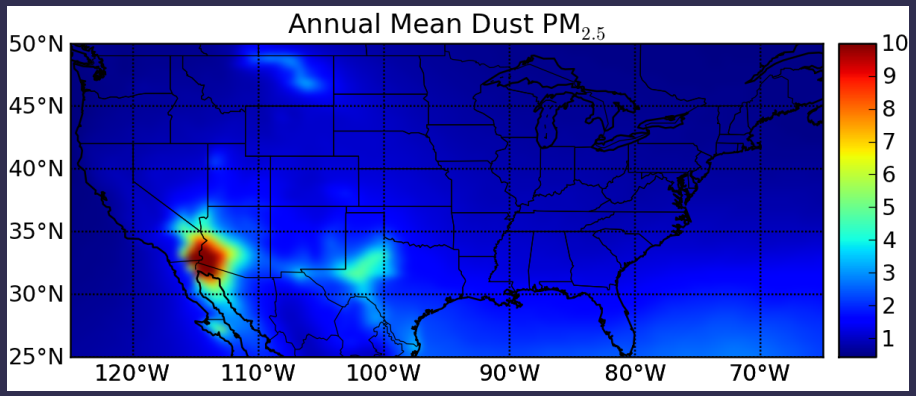
MERRAero Annual mean $PM_{2.5}$ (ug/m^3)



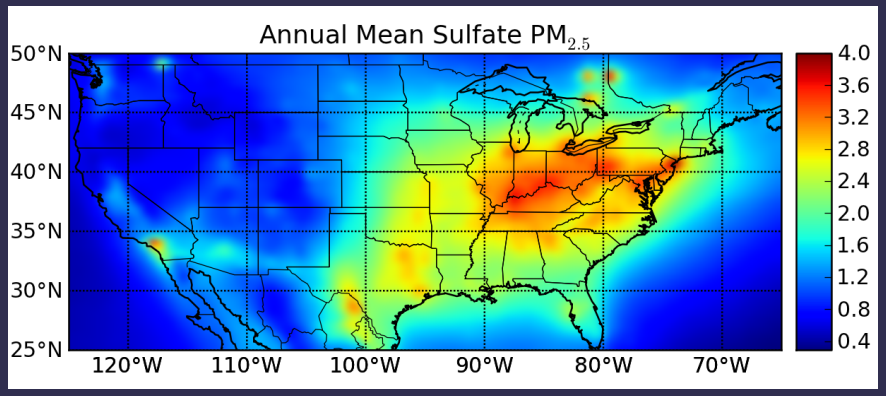
→ Carbonaceous from anthropogenic and biomass burning sources



→ Too much penetration in land



→ Dust from local sources

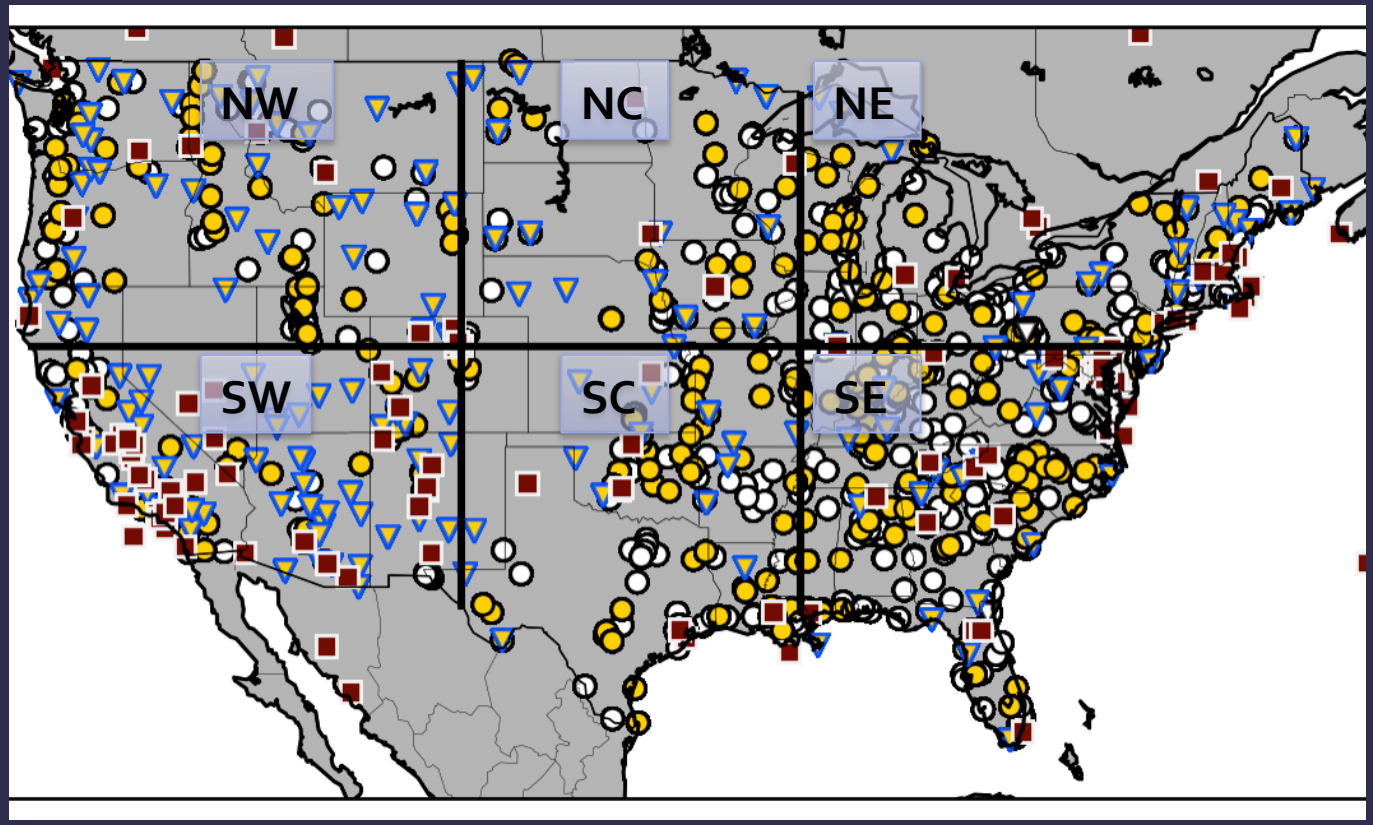


→ High values of sulfate in the Ohio River Valley due to abundance of SO_2 emitted by several power plants

Nitrate is also a component of PM2.5: nitrate particle formation is not considered in MERRAero.

Evaluation of Surface PM2.5 (2)

AOD (AERONET) & $PM_{2.5}$ measurements (IMPROVE and EPA networks)



AERONET

EPA AQS

IMPROVE

SUBURBAN
RURAL

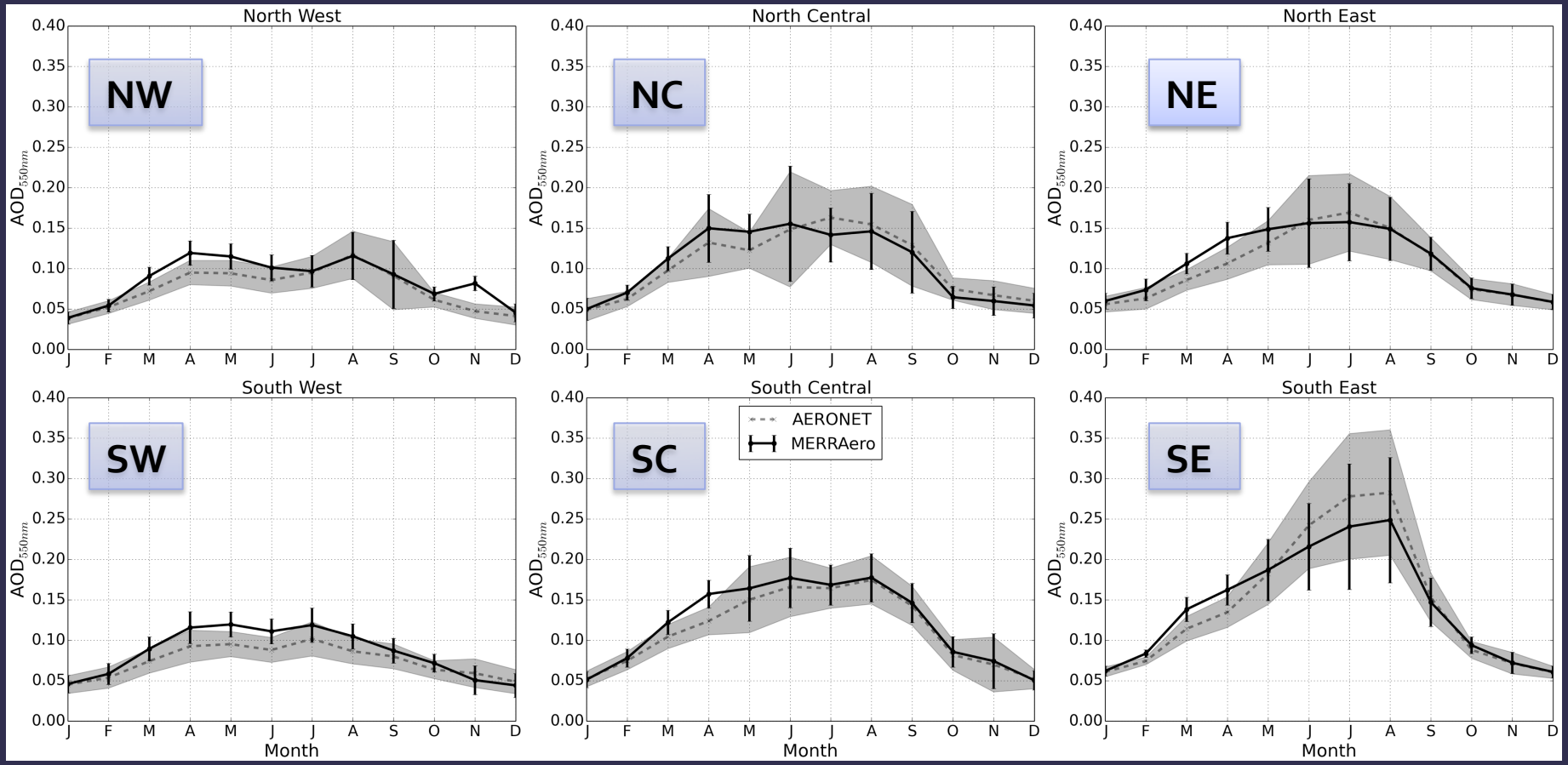
IMPROVE stations → mainly RURAL & more spread across the country.
EPA AQS stations → Eastern region

-> Comparisons by regions

Evaluation of Surface PM2.5 (3)

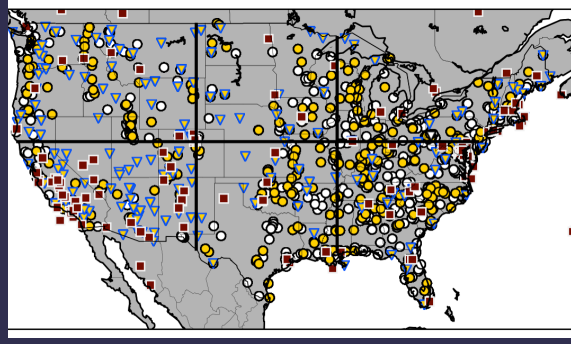
AERONET comparisons:

AOD 550 nm Seasonal variability

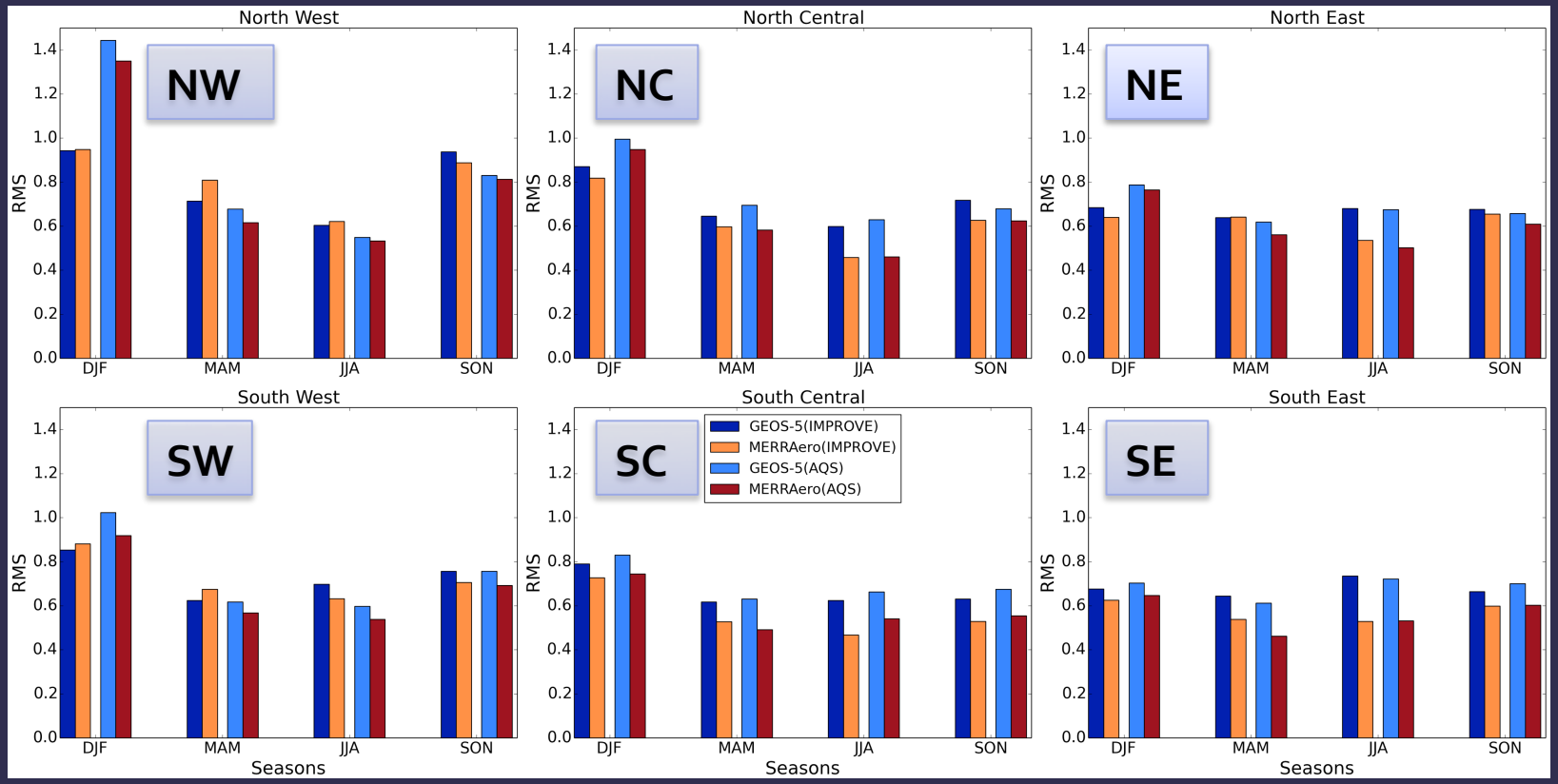


→ MERRAero AOD seasonal cycles follows AERONET seasonal cycles

Evaluation of Surface PM2.5 (4)



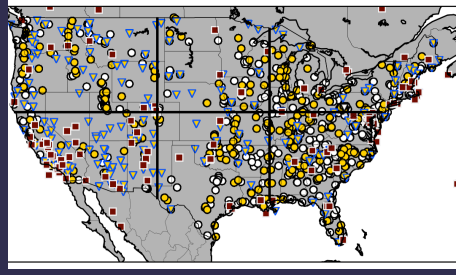
$PM_{2.5}$ - Impact of AOD assimilation



Seasonal and regional RMS of the differences (model - observation) for MERRAero and the GEOS-5 model without AOD assimilation. MERRAero and GEOS-5 sampled at IMPROVE and EPA-AQS stations.

→ Positive impact on surface PM2.5 with RMS generally lower for MERRAero.

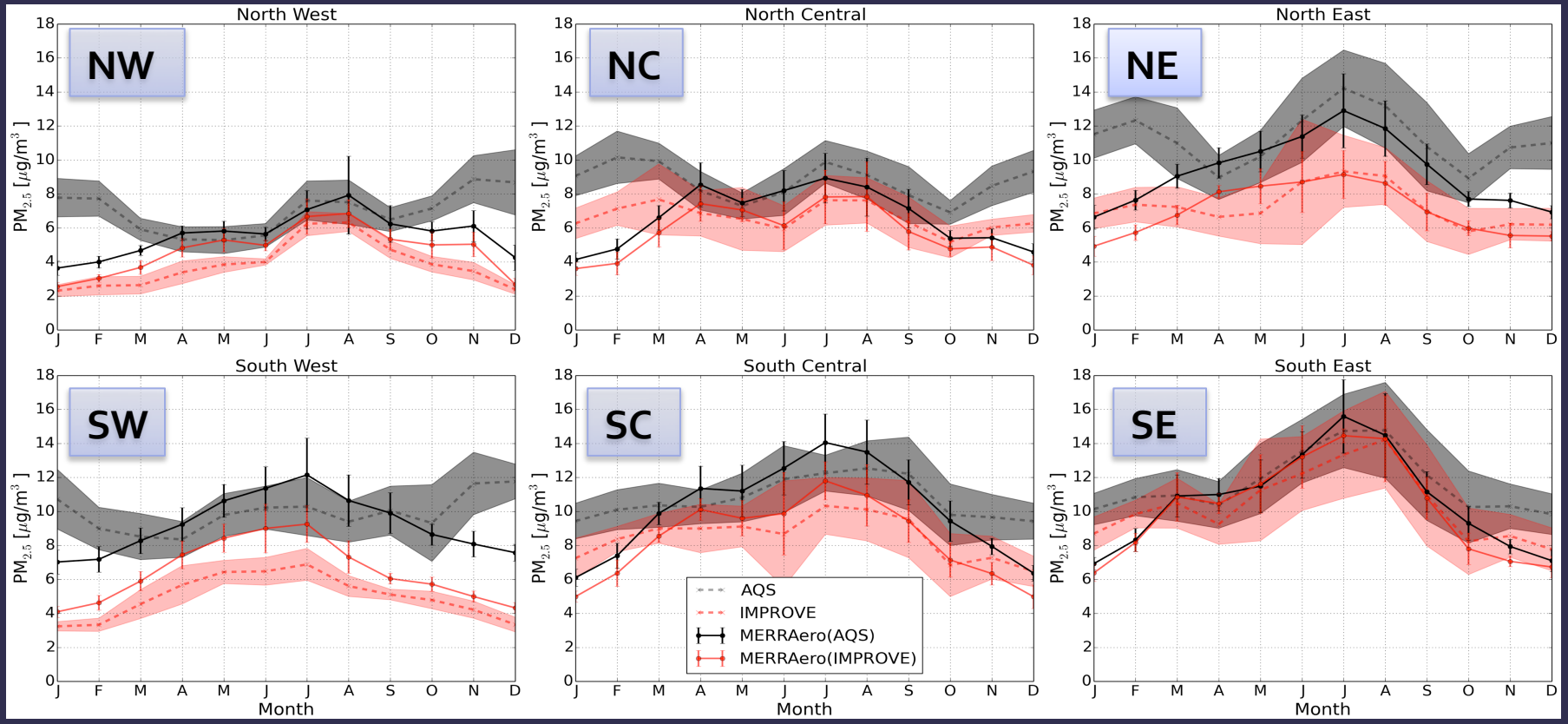
Evaluation of Surface PM2.5 (5)



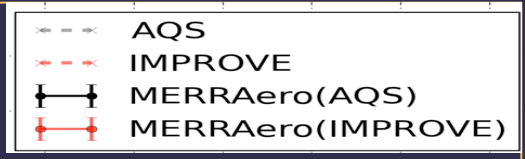
$PM_{2.5}$ Seasonal variability

Total PM2.5

For quality control: buddy check of Dee et al. (2001)

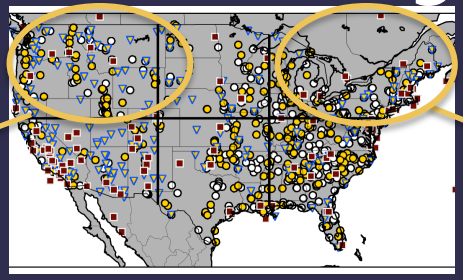


- IMPROVE and EPA $PM_{2.5}$ highly correlated, except in the Western regions.
- IMPROVE → lower values of $PM_{2.5}$ → mostly rural stations.
- MERRAero $PM_{2.5}$ better correlated with IMPROVE stations.
- Compared to EPA: better agreement during the summer; bias during the winter.



Evaluation of Surface PM2.5 (6)

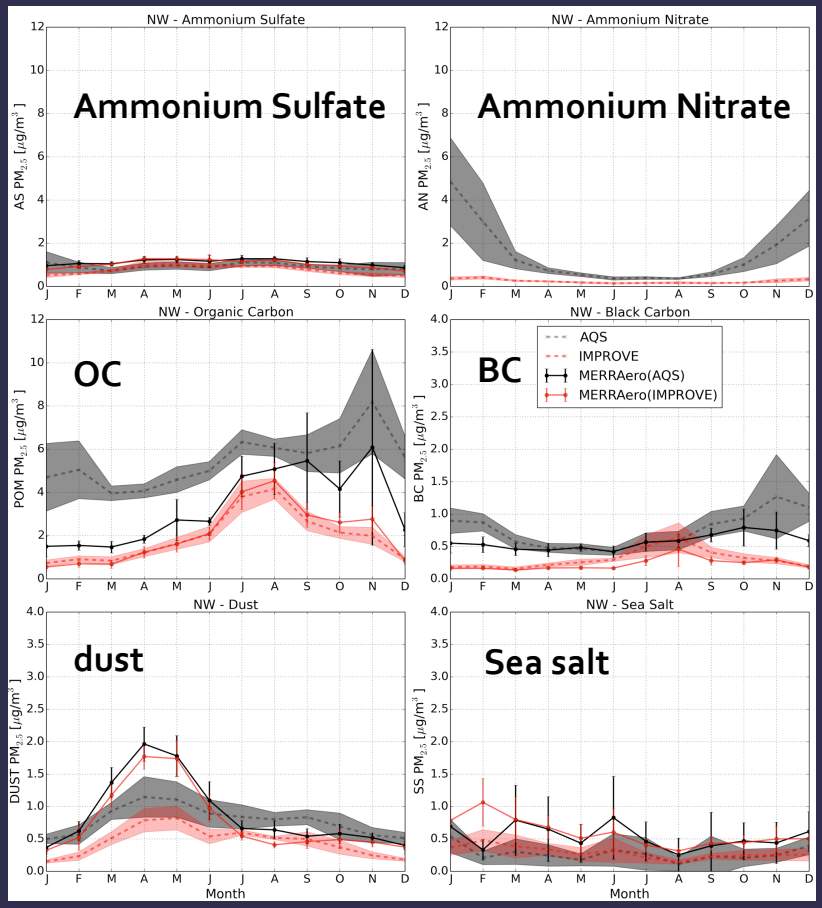
$PM_{2.5}$ – per species

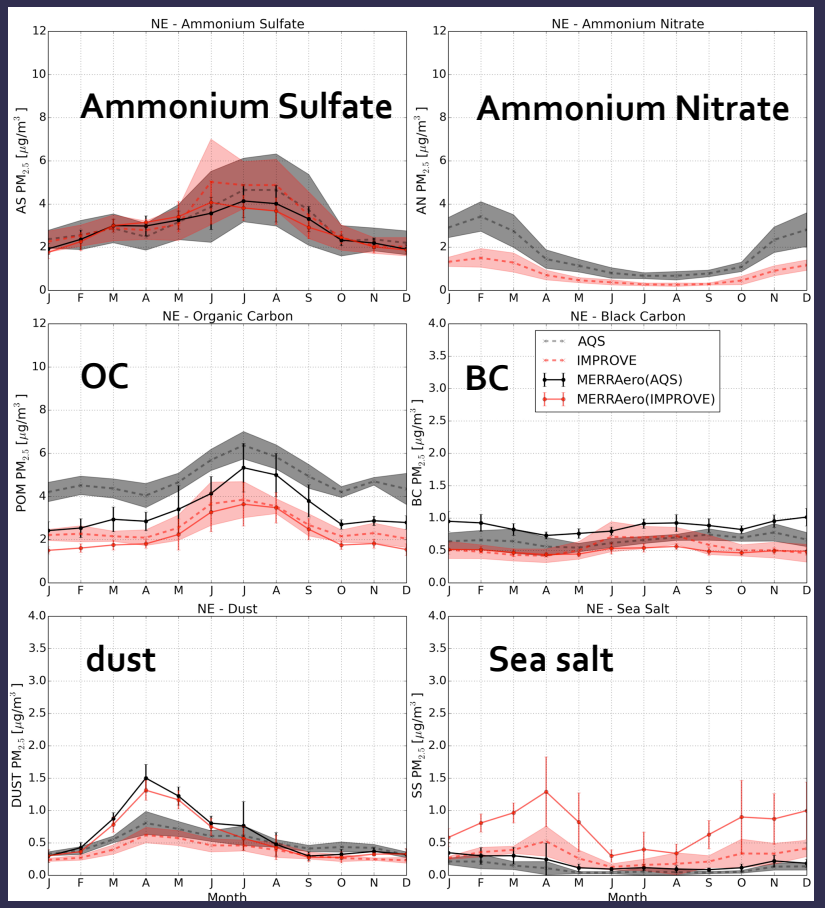


AQS
IMPROVE
MERRAero(AQS)
MERRAero(IMPROVE)

NW

NE





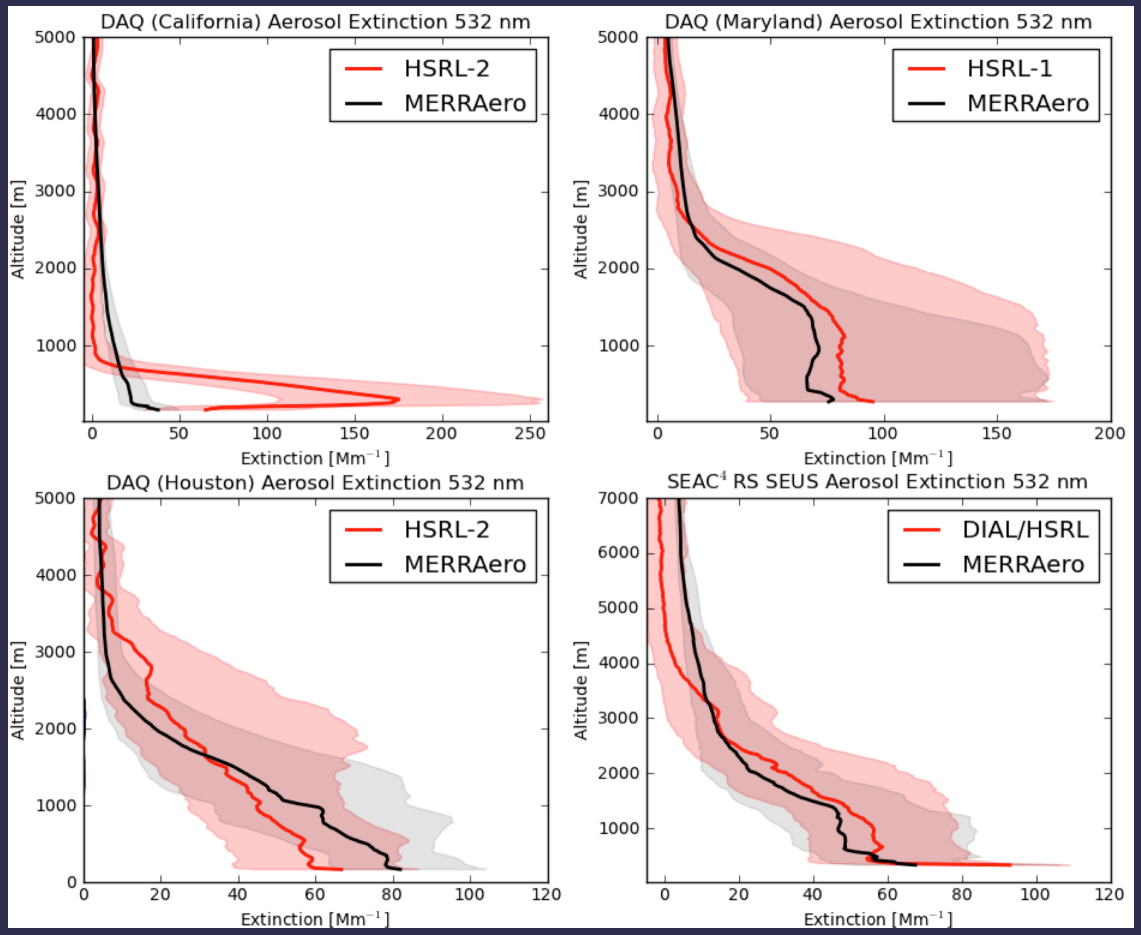
→ Lack of nitrate and underestimation of source emissions of OC over suburban areas.

Conclusions

- MERRAero : Assimilation of bias corrected MODIS AOD. It does not assimilate any data capable of directly constraining its vertical placement or composition.
- Evaluation of Absorption:
  - Absorption AOD is not assimilated,
    - Good agreement for dust after tuning of optical properties.
- Evaluation of PM2.5:
  - Comparisons with independent AERONET AOD:
    - Seasonal AOD variability captured
  - Comparisons with $PM_{2.5}$ observations:
    - Better agreement with IMPROVE (mostly rural stations), magnitude and seasonal cycle are generally in good agreement, particularly for the summer.
    - Some discrepancies during the winter are species dependent, in particular lack of nitrate and underestimation of OC. MERRAero vertical structure might also be part of these discrepancies.
- Future work:
  - Development of an Ensemble Kalman Filter based scheme for the aerosol data assimilation.

Evaluation of Surface PM2.5 (7)

MERRAero Vertical structure



Houston (August-September 2013),
California (January-Februray 2013),
Baltimore-Washington, D.C. (July 2011)

SEAC⁴RS (August-September 2013)

HSRL and modeled extinction profiles during DISCOVER-AQ and SEAC4RS field campaigns.